AFCRL- 68-0367

AD 675155

Multiple Scattering of Laser Light in the Atmosphere

by

Gilbert N. Plass
George W. Kattawar
Charles N. [illegible]s

Southwest Center for Advanced Studies
Dallas, Texas 75230

Contract No. F19628-68-C-0181

Project No. 4144

Task No. 414426
N/A

FINAL REPORT

Period Covered: December 15, 1967 - June 15, 1968

15 July 1968

Contract Monitor
Robert W. Fenn
Optical Physics Laboratory

Distribution of this document is unlimited. It may be released to the Clearinghouse, Department of Commerce, for sale to the general public.

Prepared for

AIR FORCE CAMBRIDGE RESEARCH LABORATORIES
OFFICE OF AEROSPACE RESEARCH
UNITED STATES AIR FORCE
BEDFORD, MASSACHUSETTS 01730

25

AFCRL- 68-0367

Multiple Scattering of Laser Light in the Atmosphere

by

Gilbert N. Plass
George W. Kattawar
Charles N. Adams

Southwest Center for Advanced Studies
Dallas, Texas 75230

Contract No. F19628-68-C-0181

Project No. 4144

Task No. 414426
N/A

FINAL REPORT

Period Covered: December 15, 1967 - June 15, 1968

15 July 1968

Contract Monitor
Robert W. Fenn
Optical Physics Laboratory

Distribution of this document is unlimited. It may be released to the Clearinghouse, Department of Commerce, for sale to the general public.

Prepared for

AIR FORCE CAMBRIDGE RESEARCH LABORATORIES
OFFICE OF AEROSPACE RESEARCH
UNITED STATES AIR FORCE
BEDFORD, MASSACHUSETTS 01730

MULTIPLE SCATTERING OF LASER LIGHT IN THE ATMOSPHERE

Final Report

Gilbert N. Plass
George W. Kattawar
Charles N. Adams

Abstract

A Monte Carlo Method is used to calculate the path of photons in a real atmosphere that were emitted by a laser source. The photons are emitted uniformly within a cone by the source. They undergo collisions with the molecules and aerosols in the atmosphere. At each collision either molecular (Rayleigh) scattering or absorption or aerosol (Mie) scattering or absorption may occur. The Mie single Scattering function is calculated from the Mie theory for a size distribution of spherical particles. The atmosphere is divided into a number of layers, each of which may have different properties. Reflection from both a target area and the background at the earth's surface is calculated for various target and background albedos assuming a Lambert surface. The radiance at a number of detectors at arbitrary locations within the atmosphere is calculated.

INTRODUCTION

Problems which involve the multiple scattering of photons in the earth's atmosphere are so complex that it has been possible to treat these problems in the past only by making numerous unrealistic simplifying assumptions. However, with the present generation of electronic computers and the use of sophisticated statistical techniques, it is possible to obtain realistic solutions to these problems using models which simulate accurately the many varied features of the real atmosphere.

In previous papers which have been supported by the Air Force Cambridge Research Laboratories the authors have described their Monte Carlo method[1] and applied it to studying the variation of the reflected and transmitted light from clouds as a function of the thickness of the clouds[2]. The influence of absorption on the radiation field was studied by this method[3] as was the influence of various particle size distributions for the water droplets[4]. A realistic model of the earth's atmosphere was used to calculate the radiation field at a number of different wavelengths from the ultraviolet to the infrared[5]. Finally we have extended our Monte Carlo code to include the four by four scattering matrix and the four component Stoke's vector so that polarization effects may also be calculated[6]. In all of these problems all quantities are assumed constant on a horizontal plane.

When a beam of narrow angular dimensions such as a laser is the source of the radiation, the radiation field is now a function of all three of the spatial coordinates. Our earlier Monte Carlo code was changed to include this case. All of the possible interactions of the photons with the molecules and aerosols of the atmosphere and with the earth's surface are included in the calculation. A given photon is followed until it no longer makes a contribution to any detector.

METHOD

The light from the laser source is emitted into a cone with half-angle $1/2\psi_S$. In our program the photons are emitted at all angles within the cone in such a manner that the intensity is uniform throughout any cross sectional area perpendicular to the axis of the cone. The light from the source strikes the earth's surface forming in general an elliptical spot of light. The ellipse, of course, degenerates into a circle when the beam is pointed straight down.

Similarly the receiver counts photons which are within its cone of acceptance with half-angle $1/2\psi_R$. The receiver views an elliptical spot on the ground. The receiver may be at any location in the atmosphere and not necessarily at the location of the source. Regardless of its location an option in the program may be used which automatically points the axis of the acceptance cone of the receiver so as to coincide at the ground level with the axis of the cone of the emitted light from the source. It should be noted that when the receiver and source are separated that the ellipse seen by the receiver on the ground can not coincide at all places with the illuminated ellipse on the ground. The beamwidth of both the source and receiver as well as the angle at which the source and receiver are pointed are input parameters in the program.

The photon path is followed accurately in three dimensions after emission. Monte Carlo procedures are used whenever a choice must be made in the events which may happen to the photon. After emission the point of first collision of the photon is chosen as appropriate for the optical depth along the path. The optical depth is the total cross section for all events which may happen to the photon integrated with respect to the distance parameter.

Either the photon makes its first collision in the atmosphere or at the earth's surface. In the latter case the photon is reemitted according to Lambert's law according to which the intensity of the light reflected from a surface is the same in all directions. If the first collision of the photon is in the atmosphere, the program first calculates whether or not the collision point is within the acceptance cone of the receiver. If it is outside the cone, there is no contribution to the receiver. If it is within the cone, the intensity contribution at the receiver is calculated taking into account the appropriate single scattering function and the distance from the point of collision to the receiver. Next a scattering angle for the photon is chosen from the cummulative distribution function for the appropriate type of scattering event. The new three-dimensional path of the photon is determined. The next collision point is determined and the process described above is repeated.

When the photon is traveling in an upward direction, the method of forced collisions is used, so that the photon is never actually lost by passing through the top boundary of the atmosphere. A weight is associated with each photon. This weight, which is initially unity, is adjusted whenever a forced collision is made so that the probabilities are correct. Region importance numbers are also used. If a photon enters a region far from the source and receiver, the trajectories of a predetermined fraction of the photons are terminated, while the remainder continue with an appropriate adjustment of their weight. All photons are tracked until their weight falls below a predetermined number, usually taken as 10^{-5}. Thus the photons may make many collisions within the atmosphere and also many collisions with the earth's surface before the trajectory is terminated. This method assures that all higher order collisions which may contribute to the intensity are included in the calculation.

A realistic model of the earth's atmosphere is used in these calculations[5]. The atmosphere is divided into a number of layers with different properties for each layer. Both molecular (Rayleigh) scattering and absorption are taken into account as well as aerosol (Mie) scattering and absorption. The ratios of these various events are specified for each layer. The single scattering function for the aerosols is obtained from the Mie theory by integrating over an appropriate size distribution. The Rayleigh scattering function is used for molecular scattering.

RESULTS

The single scattering function was calculated for aerosols having a size distribution appropriate to the Haze C model[7] and for the wavelength of 1.06μ. The number of aerosols at ground level was chosen so that the ground visibility was 25 km. The index of refraction of the aerosols was n = 1.50. The Elterman vertical distribution[8] of aerosols was used. The atmosphere was divided into a number of layers so that the correct amount of aerosol and molecular scattering and absorption occurred in each layer.

The half angle of both the detector and receiver was chosen as $\psi_S = \psi_R = 0.07$ rad. In the results given here, the beam was pointed straight down or at angles of 25° and 60° to the vertical. The detector was either coincident with the source or 30 m off axis in the same horizontal plane. In the latter case the axis of the acceptance cone of the receiver intersected the ground at the same point as the axis of the incident cone of light from the laser.

The results are shown in Table I. The first column shows the height in meters of source and detector. The second column shows the angle made by the direction of the source with the vertical. In all these cases the detector was centered on the intersection of the axis of the laser beam with the ground. Runs were made for the four combinations of target and background albedos of unity and zero. The albedo of the background is shown in the third column. The next four columns are the radiances when the detector and source are coincident; the values when the detector is 30 m off axis are given in the last part of the table. The quantity I_o is the radiance observed by the detector from photons that have made one or more collisions in the atmosphere, but have not yet reached the ground. The quantity I_1 is the corresponding radiance for photons which have hit the ground exactly once, regardless of the number of collisions which they have suffered in the atmosphere (this assumes a ground albedo of unity). The photons which make more than one collision with the ground were also tabulated by the computer and used in the calculation of the total radiance, but are not shown in this table. The sixth and seventh columns show the radiance for a target albedo of unity and zero respectively. The target is assumed to have the same size and shape as the laser spot upon the ground. All quantities are normalized so that they record the radiance received at the detector per unit time and area per unit source intensity per unit time.

A comparison of I_o and I_1 indicates how clearly the signal from the target can be received in a given situation. Unless $I_1 \gg I_o$ there will be difficulty distinguishing the radiation reflected from the target from that scattered by the atmosphere. When the detector is coincident with the source, Table I shows that I_o is larger than or of the same order as I_o for altitudes of 3000 m and below. In these cases I_o is reduced by two to three orders of magnitude by placing the detector 30 m off axis. The reasons for this are connected with the maximum in the single scattering function for aerosols for scattering through 180° and the decrease in the common scattering volume as source and receiver are separated. The single scattering function is considerably lower just a few degrees away from the exact backward direction. Thus placing the detector a few degrees off axis reduces the back scattering from aerosols by several orders of magnitude. Thus an important conclusion of this work is that the detector should definitely not be placed at the same location as the source.

The quantity I_i is virtually the same in all cases regardless of whether the detector is on axis or 30 m off axis. However, it is I_c that is reduced dramatically when the detector is moved off axis for the reason already mentioned. All radiances decrease as the source and detector heights are increased because of both the distance factor and the increased atmospheric absorption and scattering over the longer path.

The difference between the radiances for a target albedo of unity and zero also shows how easily a target could be detected in given conditions. Again there are much larger differences between these two numbers for the case of the detector off axis by 30 m than for the detector on axis.

TABLE I. RADIANCE

Height	Angle	$A_{background}$	I_o	I	I $A_{target}=1$	I $A_{target}=0$
			Detector on axis.			
600 m	0°	1	3.6 E-6	8.2 E-7	4.4 E-6	3.6 E-6
		0	4.2 E-6	8.1 E-7	5.1 E-6	4.2 E-6
3000		1	1.9 E-7	2.9 E-8	2.2 E-7	1.9 E-7
		0	2.9 E-8	2.9 E-8	5.8 E-8	2.9 E-8
9000		1	1.7 E-10	3.3 E-9	3.5 E-9	1.7 E-10
		0	1.3 E-10	3.3 E-9	3.5 E-9	1.3 E-10
18000		1	3.0 E-11	8.6 E-10	9.0 E-10	3.0 E-11
		0	3.6 E-11	8.6 E-10	9.0 E-10	3.6 E-11
600	25°	1	8.1 E-6	6.0 E-7	8.7 E-6	8.1 E-6
		0	2.0 E-6	5.8 E-7	2.6 E-6	2.0 E-6
3000		1	3.3 E-7	2.1 E-8	3.5 E-7	3.3 E-7
		0	6.3 E-7	2.0 E-8	6.5 E-7	6.3 E-7
9000		1	1.3 E-10	2.4 E-9	2.6 E-9	2.1 E-10
		0	1.6 E-10	2.3 E-9	2.5 E-9	1.6 E-10
18000		1	3.2 E-11	6.3 E-10	6.6 E-10	5.0 E-11
		0	2.4 E-11	6.1 E-10	6.4 E-10	2.4 E-11
600	60°	1	2.9 E-6	9.5 E-8	3.0 E-6	2.9 E-6
		0	1.9 E-6	8.6 E-8	2.0 E-6	1.9 E-6
3000		1	4.5 E-7	3.0 E-9	4.5 E-7	4.5 E-7
		0	8.3 E-8	2.8 E-9	8.6 E-8	8.3 E-8
9000		1	1.1 E-9	3.6 E-10	1.4 E-9	1.1 E-9
		0	3.4 E-10	3.3 E-10	6.7 E-10	3.4 E-10
18000		1	1.8 E-11	9.6 E-11	1.2 E-10	2.5 E-11
		0	3.6 E-11	8.8 E-11	1.2 E-10	3.6 E-11
			Detector off axis 30 m.			
600	0°	1	6.1 E-9	8.1 E-7	8.2 E-7	6.1 E-9
		0	5.0 E-9	8.1 E-7	8.1 E-7	5.0 E-9
3000		1	1.8 E-9	2.9 E-8	3.1 E-8	1.8 E-9
		0	2.0 E-9	2.9 E-8	3.1 E-8	2.0 E-8
9000		1	1.5 E-10	3.3 E-9	3.5 E-9	1.5 E-10
		0	1.3 E-10	3.3 E-9	3.4 E-9	1.3 E-10
18000		1	3.0 E-11	8.6 E-10	9 0 E-10	3.0 E-11
		0	3.6 E-11	8.6 E-10	9.0 E-10	3.6 E-11
600	25°	1	6.2 E-9	6.0 E-7	6.0 E-7	1.2 E-8
		0	5.6 E-9	6.0 E-7	6.0 E-7	5.6 E-9
3000		1	1.9 E-9	2.1 E-8	2.3 E-8	2.6 E-9
		0	2.0 E-9	2.0 E-8	2.2 E-8	2.0 E-9
6000		1	1.2 E-10	2.4 E-9	2.5 E-9	1.9 E-10
		0	1.4 E-10	2.3 E-9	2.5 E-9	1.4 E-10
18000		1	2.4 E-11	6.3 E-10	6.6 E-10	4.2 E-11
		0	2.4 E-11	6.1 E-10	6.4 E-10	2.4 E-11
600	60°	1	1.1 E-8	9.5 E-8	1.0 E-7	1.7 E-8
		0	1.2 E-8	9.1 E-8	1.0 E-7	1.2 E-8
3000		1	3 E-9	3.0 E-9	6.1 E-9	3.3 E-9
		0	3.2 E-9	2.8 E-9	5.9 E-9	3.2 E-9
6000		1	6.5 E-11	3.6 E-10	4.2 E-10	9.1 E-11
		0	6.8 E-11	3.3 E-10	4.0 E-10	6.8 E-11
18000		1	1.7 E-11	9.6 E-11	1.1 E-10	2.4 E-11
		0	3.8 E-11	8.8 E-11	1.3 E-10	3.8 E-11

GEOMETRY AND DESCRIPTION OF CODE

A right-hand cartesian coordinate system is used in this problem. The laser source height in meters is read into the program under the variable name SORHIT and the position coordinates of the source are taken to be (0,0,SORHIT), thus origin of the coordinate system is vertically below the laser source. The x-axis is taken in the direction of the center the laser spot on the earth's surface, if the laser is not pointed vertically downward; when the laser is pointed straight down, the direction of the x-axis is immaterial because of symmetry. The laser source is considered to be a beam with a direction given by the associated direction cosines with respect to the x-,y-, and z-axes. Because of the definition of the direction of the x-axis, the direction cosine with respect to the y-axis is always zero. The only input necessary to the code for determining the laser direction is the direction cosine with respect to the vertical z-axis, as the direction cosine with respect to the x-axis is calculated internally. The input variable for the direction cosine with respect to the z-axis is COSSOR and is limited in magnitude to a value less than or equal to 1. The value of -1 for COSSOR is for the vertically downward direction of the laser source. The beamwidth of the laser source, Ψ_S, is read into the program by assigning the value cos $(\Psi_S/2)$ to the variable SORWID. The physical geometry is further illustrated in Figure 1.

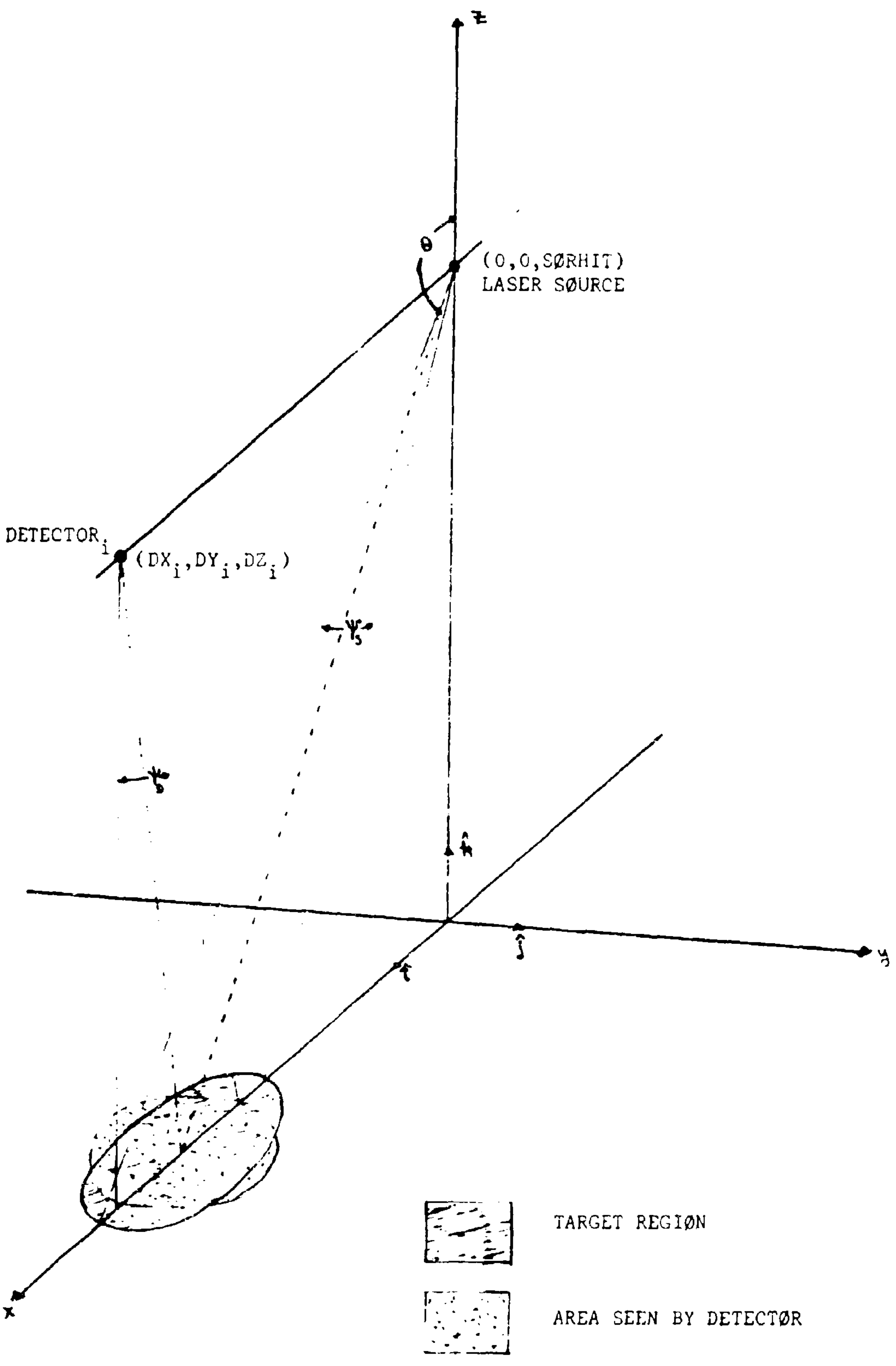

Figure 1. The physical position of laser, detector, and related variables.

A detector or series of detectors may be located on the same or different platform as the laser source as desired by the user. The number of detector to be read into the code is specified by the variable NDETEK. NDETEK may be no greater than 20 in the present code. The detectors are read into the code sequentially and are associated with some integer, say I. For the I th detector, the position coordinates are read in with the dimensioned arrays DX, DY, and DZ, thus giving the detector coordinates as (DX(I),DY(I),DZ(I)). The direction cosines are read in under the array names DU, DV, and DW, where DU(I) is the direction cosine with respect to the x-axis for the I th detector, DV(I) the direction cosine with respect to the y-axis, and DW(I) the direction cosine with respect to the z-axis. An option has been provided in the code to calculate these quantities internally if the user desires that the detector be centered upon the target area of the spot as shown in Figure 1. If the detector is to be centered upon the target area, the fields provided on the data card are left blank and the detector number is read into the group of detectors to be centered. See the list of data input to note the position of the necessary cards.

Associated with both source and detectors is the optical depth of the atmosphere below each. The optical depth of the atmosphere below the source is read into the code under the variable name TAUSOR and that of the detectors as TAUDET(I), where I = 1,2,3..., NDETEK.

The region illuminated by the undeflected portion of the incident laser beam at the earth's surface is termed the target region and is elliptical in shape. The dimensions of this region, i.e. the lengths of the semi-major and semi-minor axes, are calculated internally by the code and printed out in the resulting output. The region external to the target area is termed the background region. Each region is treated as a Lambert's surface with an associated ground albedo. The albedo of the target area is read into the code under the variable name GNDA1 and the albedo of the background region as GNDA2. The code is capable of performing calculations for two values of the target albedo at the same time; the second value of the target albedo is entered as GNDA3. The background albedo must be the same in both cases.

The atmospheric model consists of a layered medium consisting of NZONE number of zones. Each zone has variables H,TAU,RAYR,SCATR, and ABMOL associated with it. H is the height of the top of the layer as measured from the ground in meters. TAU is the total optical depth from the top of the layer to the ground. RAYR is the ratio of the total Rayleigh cross-section to the total cross-section for the region, SCATR is the ratio of the Mie scattering cross-section to the total Mie cross-section, and ABMOL the ratio of the Rayleigh scattering cross-section to the total Rayleigh cross-section. These values are determined by physical measurements at the wavelengths being used. The term Rayleigh refers to scattering and absorption by the molecular component of the atmosphere, whereas Mie refers to scattering and absorption by the aerosol component.

As required in any efficient Monte Carlo calculations, the particle is weighted to remove bias that is introduced to avoid termination of the particle due to possible transit out of the atmosphere. A collision is forced before the particle escapes the upper boundary of the atmosphere and the particles weight, denoted by the variable WAIT internal to the code, is multiplied by the probability a collision will occur before it escapes the atmosphere. A more efficient use is made in this manner of the calculated trajectories. A minimum weight is read into the code which is checked against the current value of the particle weight. The particle history is terminated when its weight falls below this minimum weight. A region importance number may also be used to terminate some of the trajectories when they enter a region far from either the source or detector.

DATA INPUT FOR LASER SCATTERING CODE

COLUMNS	VARIABLE	FORMAT	DEFINITION
CARD 1			
1-10	NPROB	I	Number of cases to be processed
CARD 2			
1-10	NZONE	I	Number of zones in atmosphere
11-20	NUMR	I	Number of RADIAL regions for importance scheme
21-30	NUMZ	I	Number of regions in z for importance scheme
CARD 3			
1-10	ALAMBD	F	Wavelength of source radiation
CARD 4			
1-10	H(I)	F	Height of layer top from ground
11-20	TAU(I)	F	Optical depth from ground to top of layer
21-30	RAYR(I)	F	σ_R/σ_T
31-40	SCATR(I)	F	σ_M/σ_{TM}
41-50	ABMOL(I)	F	σ_R/σ_{TR}
CARD 5			
1-10	LIB1	I	=1
11-20	WCO	E	Particle weight cutoff
21-30	RMIN	E	Minimum allowed distance from detector for flux contribution. Nominal value of 1.000.
CARD 6			
1-10	LIB2	I	=2
11-20	GNDA1	F	Ground albedo for target (first case)
21-30	GNDA2	F	Background albedo
31-40	GNDA3	F	Target albedo (second case)

DATA INPUT (CONT.)

COLUMNS	VARIABLE	FORMAT	DEFINITION
CARD 7			
1-10	NRD(I)	I	Region number in r I=1,...,NUMR
11-20	RGZ(I)	F	Outer radius of zone
21-30	EMPR(I)	F	Region importance number
CARD 8			
1-10	NZD(I)	I	Region number I=1,...,NUMZ
11-20	ZGZ(I)	F	Region height from ground
21-30	EMPZ(I)	F	Region importance number
CARD 9			
1-10	NMAT	I	Number of Mie distributions to be read in.
CARD 10			
1-80(10)	MAT(I)	I	Number of mu values for scattering indicatrix.
CARD 11			
1-80(10)	MAT(I)	I	Phase matrix to be used in zone I, where I=1,...,NMAT

GROUP 1 (The following group to be repeated NMAT times.)

COLUMNS	VARIABLE	FORMAT	DEFINITION
CARD A			
1-10	MO	I	Indicatrix number
11-20	NMIE1(MO)	I	Number of values in first region of cumulative probabilities.
21-30	NMIE2(MO)	I	Number of values in second region of cumulative probabilities.
31-40	DMIE2(MO)	E	Delta values for first region.
41-50	CMIE(MO)	E	Cumulative probability for region 1.
CARD B			
1-72(12)	PHANG(MO,J),J=1,NMIE1+NMIE2		Cosines for cumulative distributions.

END OF GROUP 1

DATA INPUT (CONT.)

COLUMNS	VARIABLE	FORMAT	DEFINITION
GROUP 2 (To be repeated NPROB times)			
CARD A			
1-10	LIB3	I	=3 For purpose of checking input
11-20	COSSOR	F	Direction cosine of source with respect to the z-axis.
21-30	SORWID	F	=COS ($\psi_S/2$), where ψ_S is beamwidth of source.
31-40	SORHIT	F	Height of source from ground in meters.
41-50	TAUSOR	F	The optical depth if the atmosphere below the source.
CARD B			
1-10	LIB4	I	=4
11-20	NHIST	I	The number of histories to be processed.
21-30	NDETEK	I	The number of detectors.
31-40	IXSTR	I	Starting integer for random number generator. This integer must be odd.
CARD C	I=1,...,NDETEK		
1-10	DX(I)	F	X coordinate of detector
11-20	DY(I)	F	Y coordinate of detector
21-30	DZ(I)	F	Z coordinate of detector
31-40	DU(I)	F	Direction cosine re x-axis
41-50	DV(I)	F	Direction cosine re y-axis
51-60	DW(I)	F	Direction cosine re z-axis
61-70	DETWID	F	Detector half-width = cosine of half-angle
71-80	TAUDET	F	Optical depth of atmosphere below detector
CARD D			
1-10	NZERO	I	Number of detectors to be centered upon target region.
CARD E			
1-80(10)	I=1,...,NZERO		Detector numbers to be centered.

OUTPUT FROM LASER CODE

The calculated information from the laser code is printed in a format that is easy for the user to read immediately. The first two to three pages of output show the input information which concern the model construction of the atmosphere and the Mie scattering information. This information is constant for all the cases considered and is only printed once at the beginning of the program.

The next page lists all the information with respect to the first case. The first line of printout lists information with regard to the source, i.e. the direction cosine with respect to the z-axis, etc. The second line of printout lists the number of histories processed, the number of detectors, and the starting integer for the subroutine [illegible], the random number generator. Each of the numbers printed out [illegible] for easy reading. The next few lines (the number [illegible] dependent upon the number of detectors) of printout are [illegible] each of the detectors.

Next the printout shows the dimensions of the elliptical target. The next line lists the target and background albedos for the two cases processed.

Then a series of lines is printed out to list the radiance (measured in units of energy/meter^2/$_S$ per unit source intensity /$_S$) at each detector. The radiance is listed in components as I0,I1,I2,...,I9, where I0 is the radiance contribution from photons which have not undergone a collision with the target or ground, I1 is radiance contribution from photons which have undergone only one collision with the ground, ..., and I9 is contribution for photons which have undergone at least 9 collisions with the ground or target.

The detector numbers and the total flux into each for the two different combinations of target and background albedos are listed after the above information.

Runs performed on the IBM 360/50 show that the time elapsed for a case using 8000 histories was approximately 352 seconds for the detector and source located at a height of 600 meters. Longer times are required for geometries where the source and detectors are located at larger heights.

REFERENCES

1. G. N. Plass and G. W. Kattawar, Applied Optics 7, 415 (1968).
2. G. N. Plass and G. W. Kattawar, Applied Optics 7, 699 (1968).
3. G. N. Plass and G. W. Kattawar, Applied Optics 7, 361 (1968).
4. G. W. Kattawar and G. N. Plass, Applied Optics 7, 869 (1968).
5. G. N. Plass and G. W. Kattawar, Applied Optics 7, 1129 (1968).
6. G. W. Kattawar and G. N. Plass, Applied Optics 7, (July, 1968).
7. D. Deirmendjian, Applied Optics 3, 187 (1964).
8. L. Elterman, Handbook of Geophysics and Space Environments, (S. L. Valley, Editor, Air Force Cambridge Research Laboratories, Bedford, Mass., 1965).

Unclassified
Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) Southwest Center for Advanced Studies P. O. Box [illegible] Dallas, Texas [illegible]	2a. REPORT SECURITY CLASSIFICATION Unclassified 2b. GROUP

3. REPORT TITLE

MULTIPLE SCATTERING OF LASER LIGHT IN THE ATMOSPHERE

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)
Scientific. Final. 15 December, 1967 - 15 June 1968 Approved 21 August 1968

5. AUTHOR(S) (First name, middle initial, last name)
Gilbert N. Plass
George W. Kattawar
Charles N. A[illegible]

6. REPORT DATE 15 July 1968	7a. TOTAL NO. OF PAGES 23	7b. NO. OF REFS 8

8a. CONTRACT OR GRANT NO. F19628-68-C-[illegible] b. Project, Task, Work Unit Nos. [illegible]-26 n/a c. DoD Element [illegible] d. DoD Subelement [illegible]	9a. ORIGINATOR'S REPORT NUMBER(S) 9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report) AFCRL-68-03[illegible]7

10. DISTRIBUTION STATEMENT

Distribution of this document is unlimited. It may be released to the Clearinghouse, Department of Commerce, for sale to the general public.

11. SUPPLEMENTARY NOTES TECH, OTHER	12. SPONSORING MILITARY ACTIVITY Air Force Cambridge Research Laboratories (CRO) L. G. Hanscom Field Bedford, Massachusetts 01730

13. ABSTRACT

A Monte Carlo method is used to calculate the path of photons in a real atmosphere that were emitted by a laser source. The photons are emitted uniformly within a cone by the source. They undergo collisions with the molecules and aerosols in the atmosphere. At each collision either molecular (Rayleigh) scattering or absorption or aerosol (Mie) scattering or absorption may occur. The Mie single scattering function is calculated from the Mie theory for a size distribution of spherical particles. The atmosphere is divided into a number of layers, each of which may have different properties. Reflection from both a target area and the background at the earth's surface is calculated for various target and background albedos assuming a Lambert surface. The radiance at a number of detectors at arbitrary locations within the atmosphere is calculated.

DD FORM 1 NOV 65 1473

Unclassified
Security Classification

Unclassified

Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Laser						
Multiple Scattering						
Atmospheric Transmission						
Monte Carlo Methods						
Mie Scattering						

Unclassified

Security Classification